An Effective Inter Stand Cooling in Hot Strip Mill

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INTRODUCTION

The Inter Stand Cooling at wide strip hot mills partakes fundamentally in reaching and maintaining the required exit rolling temperature (ERT). Thus it enables to reach better and more homogeneous mechanical properties of a strip, particularly in micro alloyed steels. ERT can be maintained constant on the whole strip length, even when transfer bar temperature oscillates due to skid marks in slab or other reasons. Very important is the possibility to increase the mill production so that it enables to roll at higher speed or speed up. For the correct function of the Inter Stand Cooling it is necessary to fulfill two basic requirements – to keep at disposition an optimal hardware (cooling headers with sufficient cooling power including the possibility of fast and fluent regulation of flow rate) and the advanced control software, both for cooling setup, feed forward and feedback control.

1. DETERMINATION OF ISC HEADERS COOLING EFFECTS

In Heat Laboratory, FSI VUT Brno, the methodology of determination of cooling effects during spraying hot surfaces was developed [1]. The basis is created by an experimental stand which enables study of cooling and mechanical effects of nozzles at directly moving samples. Structurally the stand is designed so that it enables progression of samples up to the weight of 50 kg with infinitely adjustable speed from 0 to 10m/s.

Figure 1. Linear laboratory stand with conic nozzles spraying

On the supporting frame there is a carriage moving, on which the sample under examination with temperature sensors and measuring system – datalogger is fixed. The carriage's progression is provided by a hauling rope through a drive pulley and a motor with a gearbox. The motor is power supplied by a frequency converter with the possibility of a smooth change of rotation speed and changeovers. The direction of the carriage can be reversed and passages repeated in a requiring number. The whole cycle is programmed and controlled through the superior PC. There is a spraying section in the central sector where the arbitrary jets configuration can be arranged (Figure 1).

1.1 Experimental Procedure of Cooling Effects Determination

The sample is fitted with thermo couples connected to the datalogger. Before the actual experiment the carriage with the sample is positioned to the utmost position and it is heated to the required temperature using an external furnace. After the stabilization, the heating device is removed, the stand is turned to spraying position, the pump gets going and the carriage's travel gets started. Signals from sensors are read by the datalogger which moves together along with the sample. At the same time, the signal indicating the actual carriage's position is sensed as well. After performing the required number of passes, datalogger's internal memory data are exported into the computer for further processing.

Information from temperature sensors (temperatures records in a particular depth under the surface) are used as entry parameters for the thermal conduction's inverse function [2]. Inverse function outputs are progressions of temperatures, heat flows and Heat Transfer Coefficients (HTC) on the heat transfer surface. Most often, in mathematical models the boundary condition of the 3rd type is used where heat flow is specified by the heat transfer coefficient value and the cooling water temperature. An example of the heat transfer coefficient distribution for various experimental conditions is introduced in Figure 2.

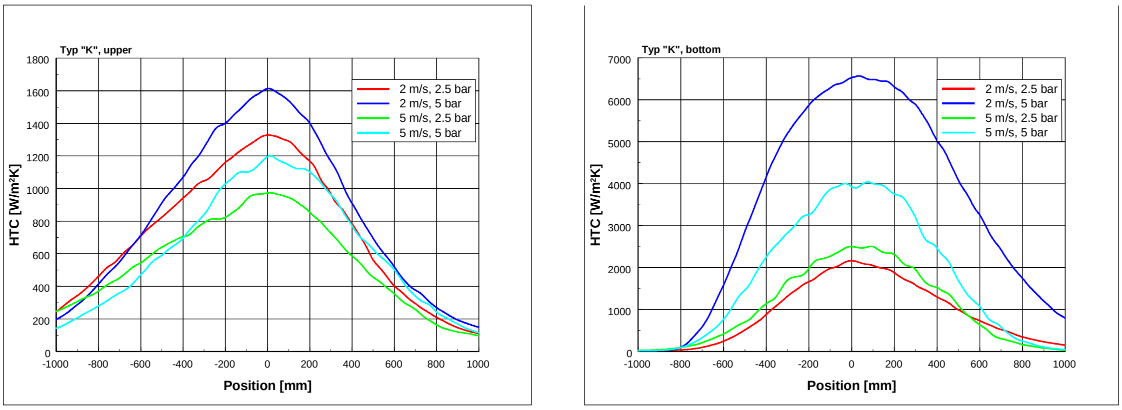

Figure 2. Progression of heat transfer coefficient for experiments with conical nozzles, upper surface (left) and bottom surface (right)

1.2 Verification of Inter Stand Cooling Effects with the Help of a Temperature Model

The Inter Stand Cooling detailed temperature model, which uses measured heat transfer boundary conditions, gives the answer whether the proposed method of cooling will meet the required parameters from the point of view of intensity and regulating range. This model is designed on the basis of knowledge of rolling mill conditions and it simulates an actual rolling campaign. Various factors influence (header type, working pressure, rolled material thickness, rolling speed) on the cooling efficiency can be verified computationally. This procedure enables to design optimal ISC headers made to measure for every hot mill or stand.

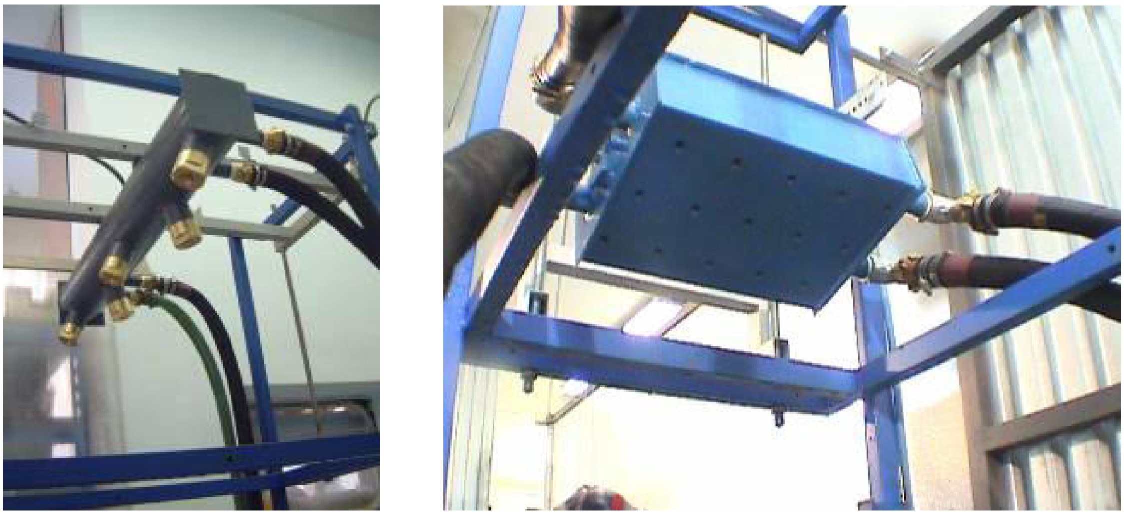

Figure 3. Various types of cooling headers (nozzles and holes)

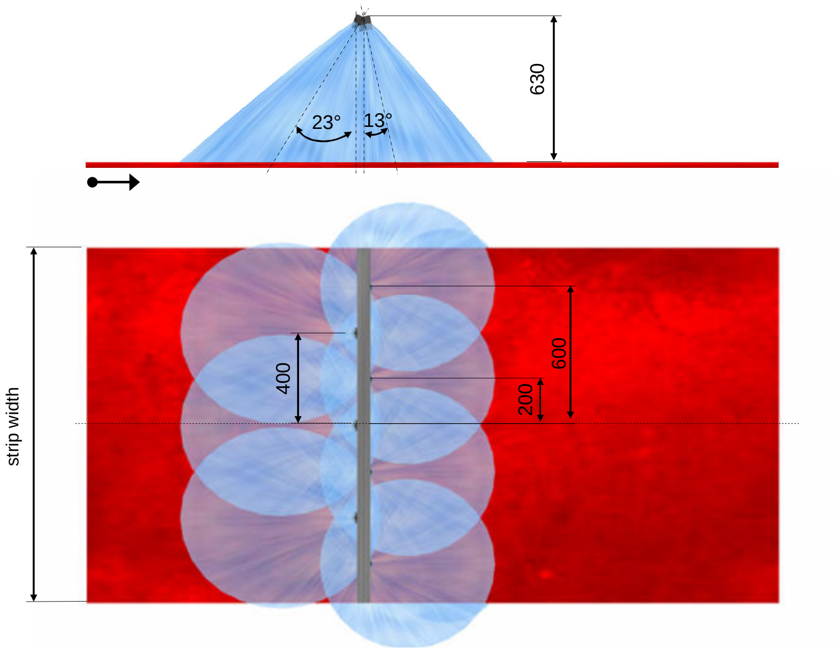

Figure 4. Designed upper header of ISC (width conical nozzles)

2. CONTROL SYSTEM OF ISC

Presented control system of ISC has been designed to work either within existing Level2 of the mill or to work rather independently of it. It consists of three basic parts – Setup (working within existing Level2 or on separate computer), Piece to piece adaptation and Long term adaptation. Basis scheme of the system is in Figure 5.

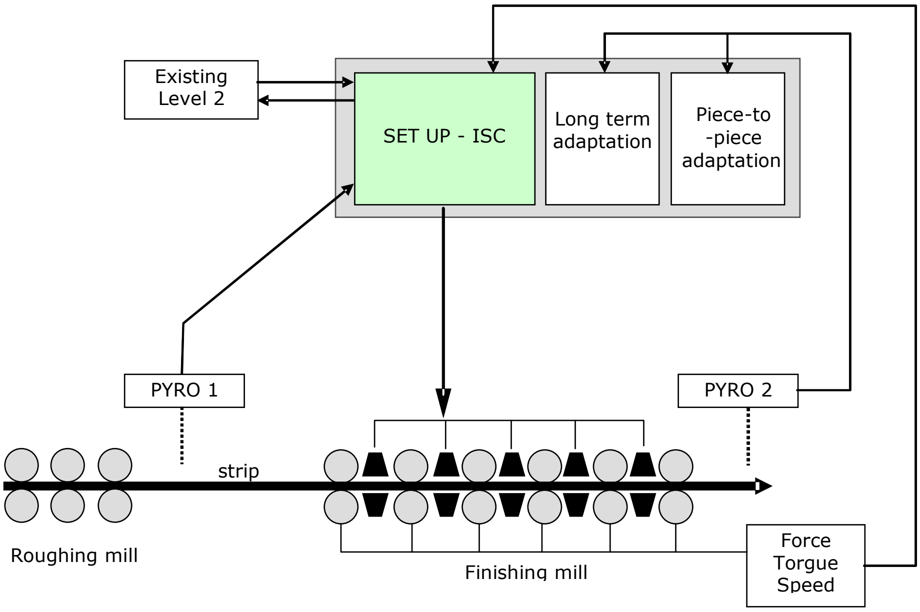

Figure 5. Basic scheme of the control system

The main task of the **Setup** is to calculate the number and power of cooling headers to reach the target temperature in the whole strip length. The measured strip temperature is mostly available only at limited number of spots, at outlet from the roughing mill, before the finishing mill and at the finishing mill outlet. Nevertheless, the temperature measuring before the finishing mill entry is usually very unreliable because it is influenced by a thick scale layer, emissivity of which strongly depend also on the steel chemical composition. As the transfer bar temperature oscillates, the number and cooling power of the headers (on terms of flow rates) must be calculated in several spots lengthwise (50 points). The points (coordinates) are situated in the local extremes of the temperature curve in the transfer bar. Special filter is used to get rid of incorrect measurements, to smooth the temperature curve and to find local extremes of the temperature behind the roughing mill. Measured deviations of the transfer bar temperature at the outlet of roughing mill can be seen in Figure 6.

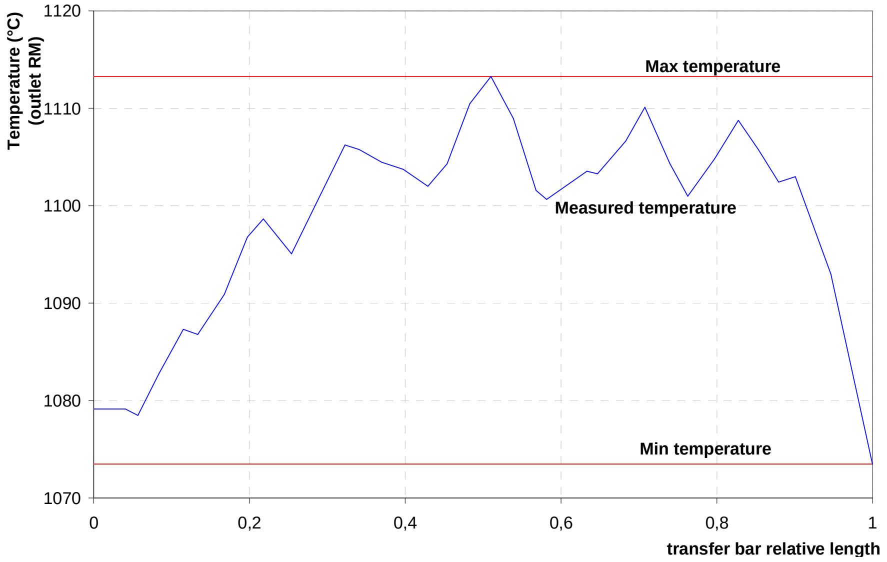

Figure 6. Measured transfer bar temperature lengthwise (example of an older furnace)

Feedback regulation is done by replaced setup. The measured temperatures are checked and if the deviation from computer values exceeds certain limit, a new setup is calculated from the remaining length of the strip. In most strips from two to five setups are calculated. Using this data the setup of headers for every spot is performed and so called cooling matrix is assembled. An example of the cooling matrix – providing number, position and cooling power of headers (in terms of normed flow rates) in every spot lengthwise can be seen in Figure 7 (see Figure 10 for position of headers). It is obvious, that the total cooling power of ISC varies lengthwise.

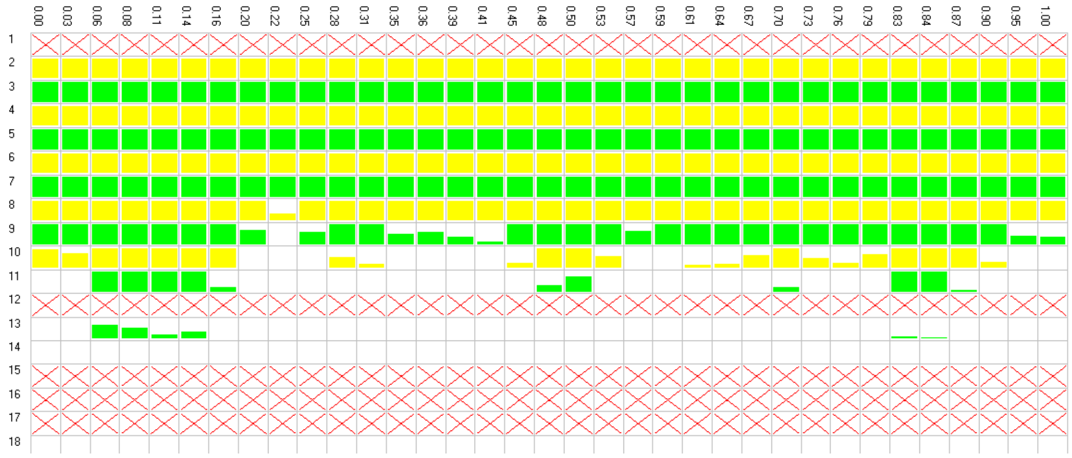

Figure 7. Cooling matrix , horizontal axis – relative strip length, vertical axis - active cooling headers (green-upper, yellow-bottom headers)

3. SOFTWARE MODULES OF ISC

3.1 Temperature Model

The temperature model has to describe the temperature field in the rolled strip for defined boundary conditions. Detailed multidimensional models can be used only in a limited way due to their demands for the processor's time. A compromise solution is 1-D physical model on the base of Finite Element Method which enables to calculate the temperature profile through the strip thickness in the given coordinate (point). The model neglects the heat conduction both across the width and along the length of the strip (Figure 8). However, understanding of the temperature along the length is very important and therefore it is necessary to calculate the temperature field in several points.

Boundary conditions cover

- Air cooling of a strip (heat radiation and convection),
- Water cooling with the help of an inter stand headers, roll cooling, descaler,
- Cooling in the rolling gap,
- Heat generation due to deformation in roll gap.

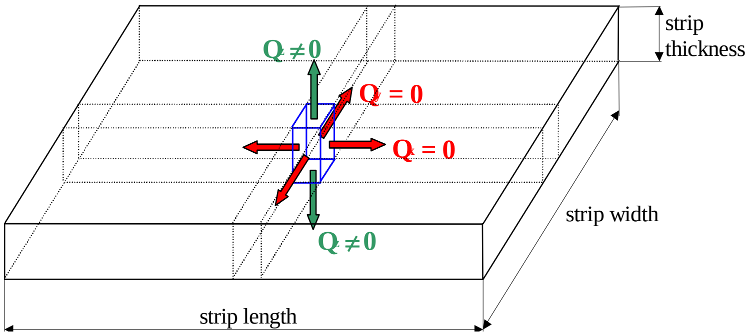

Figure 8. 1-D model scheme

3.2 Model for the Headers Setup (inverse function)

The task of the model is a fast calculation of the cooling power and number of suitable headers so that the required exit rolling temperature is reached (for one examined point on the strip). For the calculation, the optimization method Merortha predictor corrector is applied.

The algorithm scheme for one point with mutual relationship of both models is at Figure 9.

Used constraints for the optimization calculation:

- Specific power of each of the headers must vary in between 0 (off) up to 1 (max. power)
- The header’s power must be higher than or equal the next header (along the rolling course)
- The headers’ power should be distributed so that strip is being cooled most at the largest thicknesses (for some steel grades this criterion will not be applied)
- To give priority to condition off or set on the full power.

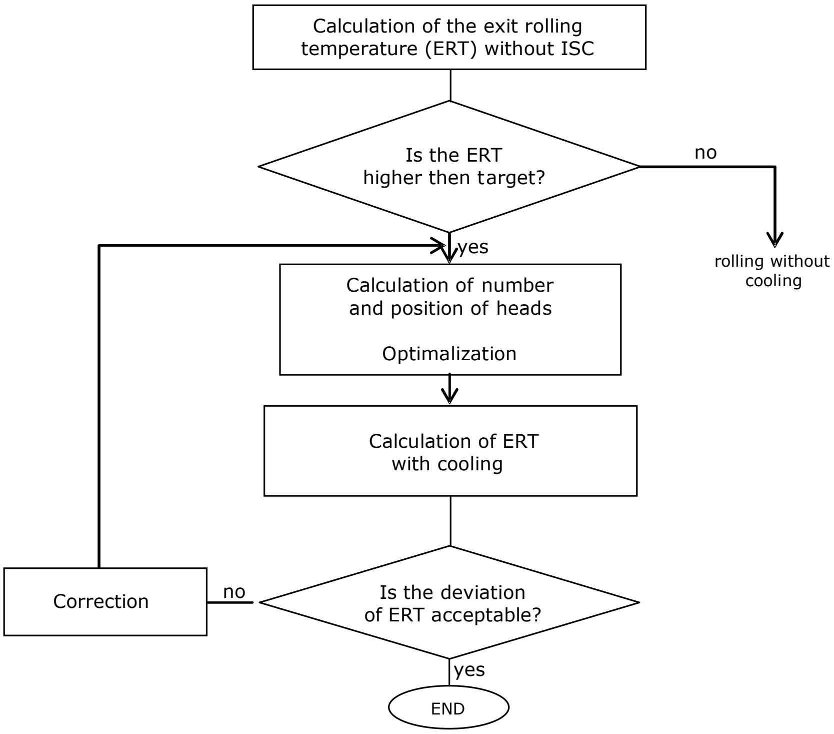

Figure 9. Headers setup algorithm for one point

4. PRACTICAL EXPERIENCE

Inter Stand Cooling possibilities were determined by measurements and mathematical simulations in three different hot strip mills (2000 mm). The scheme of finishing mill with the cooling headers is shown in Figure 10. The ultimate possible temperature drop due to interstand cooling varies from 80°C - 65°C for the thick strip (thickness > 8mm) up to 130°C - 80°C for the thin strip (thickness < 2,7 mm) in dependence of maximum flow rates on headers, number of headers and header type.

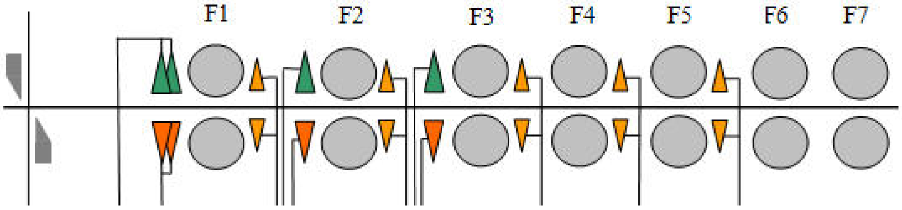

Figure 10. ISC headers position in finishing mill (an example)

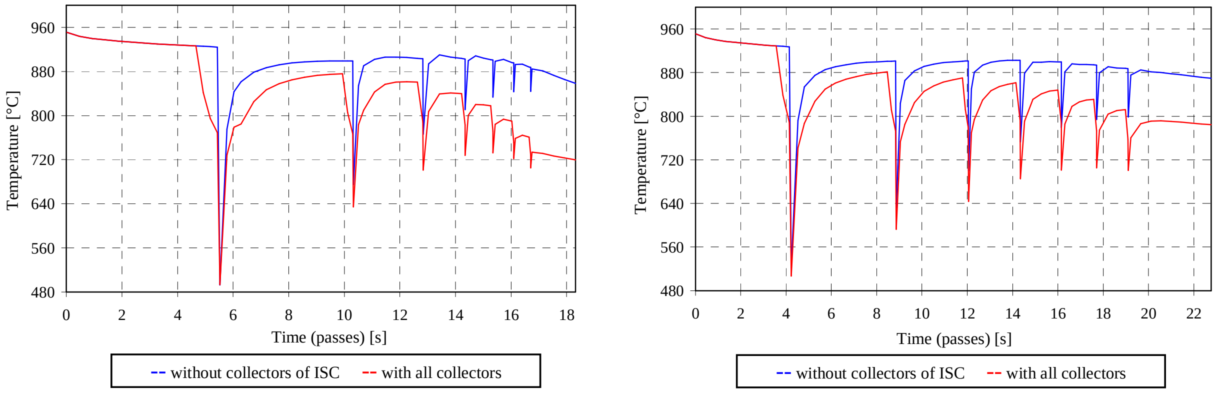

Figure 11: The efficiency of ISC in thin and thick strip

4.1 Cooling Strategies

There can be various cooling strategies applied, that can provide soft cooling, standard cooling or rapid skid mark elimination. Each of the strategies has advantages and disadvantages. Standard cooling is working with maximum cooling headers spraying with 100% flow rate. This is a very intensive cooling that removes skid marks rather late, in the last active inter stand headers. But, the most intensive cooling and maximum temperature drop can be achieved.

Rapid skid mark elimination means intermittent cooling in early stands. Skid marks can be eliminated early – in first stand but cooling efficiency of the whole system is lower. That results in lower speed up and lower mill productivity in comparison with the standard cooling strategy. In some cases the soft cooling can be used. Soft cooling is characterized by limitations of cooling power (flow rate) on certain headers.

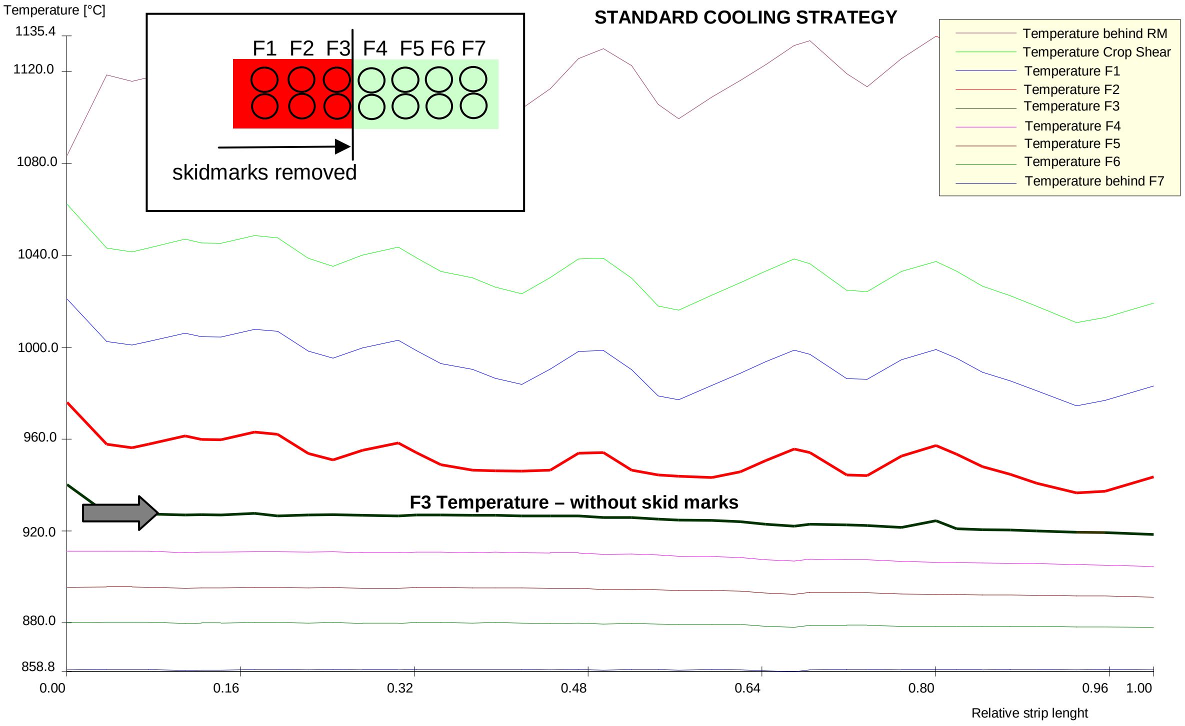

Figure 12. Comparison of early cooling and standard cooling: Standard cooling strategy

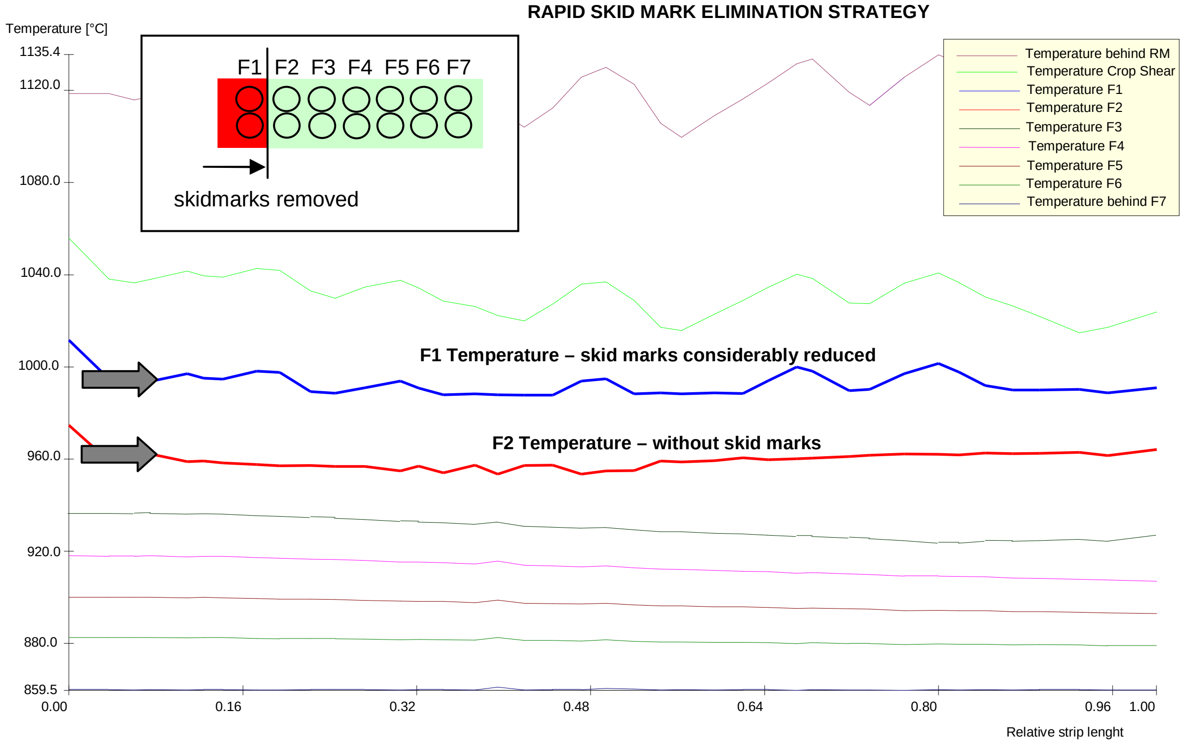

Figure 13. Comparison of early cooling and standard cooling: Rapid skid mark elimination strategy

4.2 Target Exit Rolling Temperature

The target rolling temperature (ERT) can be kept lengthwise with a tolerance of ± 10°C from the target temperature. In thin strips (< 4 mm), the temperature deviations are less than ± 7 °C on 95 % of the strip length. In thick strips (>10 mm) the tolerance ±12°C can be reached only if the temperature oscillation in transfer bar is less than 15°C. During the system testing it was discovered deviation in target temperature at strip head and tail even the body temperature was controlled very precisely. The reason for this deviation was mainly due to the incorrect transfer bar temperature since temperature measurements at these parts are very unreliable.

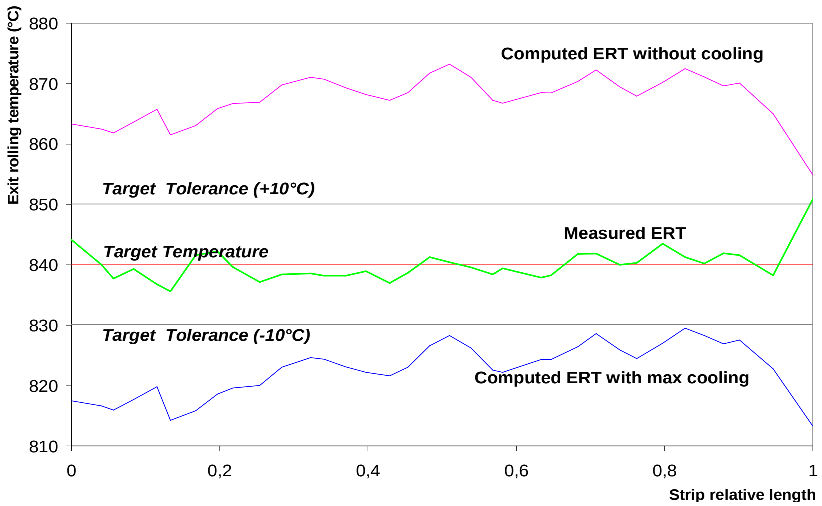

Fig. 14 Measured and Calculated ERT

4.3 Elimination of Skid Marks

ISC proved to be very effective tool to eliminate skid marks. If the slab is heated in older furnaces the temperature oscillation in transfer bar can be more than 30 - 40 °C. Those oscillations can be completely eliminated in thin strips (< 4 mm). In thick strips (more than 12 mm) temperature deviations up to 20 °C in transfer bar can be eliminated. Higher oscillations (30 - 40 °C) cannot be removed completely, but they can be considerably reduced.

4.4 Enhancement of speed/speed up

Required exit rolling temperature is one of the limiting parameters for speed and speedup of the strip. Providing that ISC has enough cooling power and flow rate on headers and can be effectively controlled the limits of speed and speedup can be raised. There are several metallurgical and technological aspects prohibiting extensive cooling in special steels where this way of increasing productivity can be used only in limited manner. Nevertheless practical experience proved an increase of productivity due to ISC when compared with rolling without ISC or using ISC with constant cooling power (flow rate) lengthwise. An example below demonstrates the cooling matrices of thin strips rolled at 14 m/s and 21 m/s. When rolling with low speed the cooling is nearly off. When rolling with higher speed up (threading velocity of both strips was the same), the ISC works with maximum power on the tail.

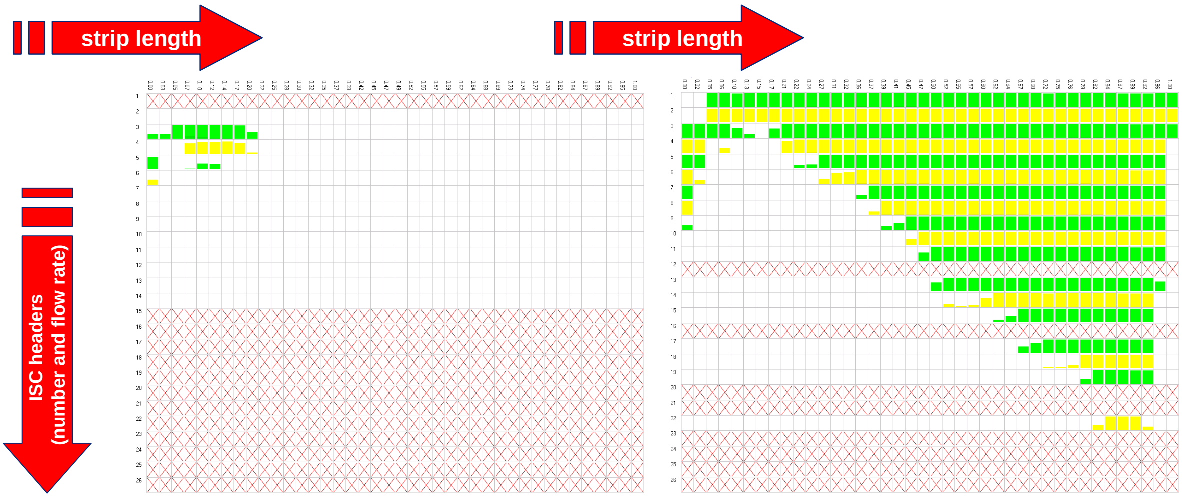

Fig. 14 Cooling matrices for rolling velocity 14 m/s (left) and 21m/s (right)

CONCLUSION

Complex approach to the Inter Stand Cooling problems was presented in this paper. Design of modern, more efficient cooling headers with help of laboratory measurements and evaluation of Heat transfer coefficient of headers have been shown. Software for control of exit rolling temperature has been shortly described together with the most important cooling strategies. Practical experience of revamped ISC has been discussed. New developed cooling strategies proved to increase productivity of the mill by higher rolling tempo. Exit rolling temperature can be kept in very narrow range. Temperature oscillations due to skid marks can be fully eliminated or considerably reduced. This helps to reduce number of temperature reclasses, enables better cooling of laminar section and achieving more homogenous mechanical properties of the strip as well as more stable rolling due to less oscillation of strip temperature and rolling speed.

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